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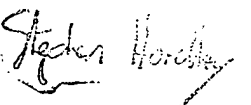
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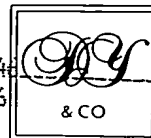
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APPARATUS FOR DETECTING AND
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APPARATUS FOR DETECTING AND RECOVERING DATA

Field of Invention

The present invention relates to methods and apparatus for detecting and recovering data embedded in information material.

5 Information material as used herein refers to and includes one or more of video material, audio material and data material. Video material in this context may be still images or moving images.

Background of Invention

10 Steganography is a technical field relating to the embedding of data into material such as video material, audio material and data material in such a way that the data is imperceptible in the material.

Watermarks are data embedded in material such as video material, audio material and data material. A watermark may be imperceptible or perceptible in the material.

15 A watermark may be used for various purposes. It is known to use watermarks for the purpose of protecting the material against, or trace, infringement of the intellectual property rights of the owner(s) of the material. For example a watermark may identify the owner of the material.

20 Watermarks may be "robust" in that they are difficult to remove from the material. Robust watermarks are useful to trace the provenance of material which is processed in some way either in an attempt to remove the mark or to effect legitimate processing such as video editing or compression for storage and/or transmission. Watermarks may be "fragile" in that they are easily damaged by processing which is useful to detect attempts to remove the mark or process the material.

25 Visible watermarks are useful to allow, for example, a customer to view an image via, for example, the Internet to determine whether they wish to buy it but without allowing the customer access to the unmarked image they would buy. The watermark degrades the image and the mark is preferably not removable by the customer. Visible watermarks are also used to determine the provenance of the material into which they are embedded.

30

In US patent 5, 930, 369 (Cox et al) it has been proposed to embed data into material such as images to form a watermark by converting the material into the transform domain and adding the data to the image in the transform domain. For the example of images and the Discrete Wavelet Transform of these images into the transform domain, the data to be added can be combined with the wavelet coefficients of one of a plurality of sub-bands which are formed in the transform domain. Generally, the data to be embedded is arranged to modulate a predetermined data sequence such as a Pseudo Random Bit Sequence (PRBS). For example, each bit of the data to be embedded is arranged to modulate a copy of the PRBS, and this copy is then added, for example into one of the sub-bands of the image in the transform domain. The image is then converted back to the spatial domain.

If it is desired to detect and recover the embedded data from the image, the image is converted back to the transform domain and the embedded data is recovered from the sub-band in the transform domain by cross-correlating the transform coefficients in the sub-band with the predetermined data sequence which is known to the detecting apparatus. Data sequences such as a PRBS have properties which provide a high auto-correlation result when the sequence coincides with itself and a low or ideally zero output at all other shifts of the sequence with respect to itself. As such, the embedded data can be recovered from the result of correlating the sub-band data with the predetermined data sequence.

Summary of Invention

According to the present invention there is provided an apparatus for detecting and recovering data embedded in information material, the data having been embedded in the information material by modulating a predetermined data sequence with the data to be embedded to form modulated data and combining the modulated data with the information material, the apparatus comprising a correlation processor operable in combination with a data sequence processor to form a correlation sequence, and a data processor operable under control of the correlation processor to correlate information material data symbols, to which the modulated data have been combined, with the correlation sequence, to form a correlation output signal representing the correlation between the information material data symbols and the correlation data sequence, and

to recover the embedded data from the correlation output signal, wherein the correlation sequence comprises a plurality of predetermined data sequence versions, each version representing a possible form of the predetermined data sequence for recovering the embedded data symbols from the information material.

5 Data representing information material such as images are often processed in order to convert the data from one form to another, so that, for example the images can be compression encoded and decoded. A further example in which images may be processed is if the images are convert into another form using transform processing. Such transforms may be for example the Discrete Wavelet Transform or the Discrete
10 Fourier or Cosine Transform. A result of processing the material, can cause the data representing the material to be shifted, in particular in the transform domain.

 If it is desired to recover the embedded data by correlating the modulated data from the transform domain with the predetermined data sequence known to a decoding data processor, it may not be possible to detect the embedded data because the
15 predetermined data sequence will no longer align with the modulated version of the predetermined data sequence, because the data in the transform domain has shifted. Effectively, the shift of the data in the sub-band will have an effect of introducing a corresponding relative shift between the correlating predetermined data sequence and the modulated version of the data sequence in the sub-band. The correlation output
20 signal may be low or zero, thereby preventing the data from being correctly detected.

 Similarly, the predetermined data sequence which is modulated by the data to be embedded and combined with the information material may be one of a set of predetermined data sequences. The predetermined data sequence used to embed the data in the information material may be unknown at the decoder.

25 Embodiments of the present invention provide an improvement in the likelihood of correctly detecting the embedded data by generating a correlation sequence comprising a plurality of predetermined data sequence versions. Each version may be the same predetermined data sequence but shifted with respect to one another. Each shift provides a possible relative shift of the material data in the
30 transform domain at which there would be no shift between this version and the modulated version of the data sequence in the transform domain. A result of the correlation will produced a high output signal value, which when compared with a

predetermined threshold provides an indication of the embedded data symbol. All other versions of the predetermined data sequence in the correlation data sequence will produce a low correlation output or zero, and so will not interfere with the detection of the embedded data symbol. This is because predetermined data sequences such as PRBSs have such correlation properties that the other shifted versions of the PRBS will represent noise with respect to the correlation with the wanted signal. Therefore provided the correlation output signal is high enough in the presence of the other shifted versions the embedded data symbol can be detected from the transform domain data in spite of any shifts of the transform domain data. Generally, it is not necessary to know which of the shifted versions in the correlation data sequence aligns with the predetermined data sequence of the embedded data.

In preferred embodiments, the number of versions of the predetermined data sequence may be equal to a number of possible relative shifts of the modulated predetermined data sequence, each of the plurality of predetermined data sequences being shifted with respect to each other, each shift representing a number of symbols by which the modulated data symbols may have shifted in the transform domain.

In alternative embodiments, in which the predetermined data sequence used to form the modulated data is one of a set of predetermined data sequences, each of said predetermined data sequence versions of the correlation data sequence is a different predetermined data sequence of the set of possible predetermined data sequences which may have been used to form the modulated data. As will be appreciated, the wanted predetermined data sequence which corresponds to the predetermined data sequence used to be embed the data will produce a correlation result from which the embedded data can be recovered, whereas the other sequences will form noise. The embedded data may be recovered therefore, without knowing which of the predetermined data sequences was used to embed the data.

In preferred embodiments, the correlation sequence may be formed by selecting versions of the predetermined data sequence and reversing the polarity of the selected versions of the predetermined data sequence. It has been found that by reversing the polarity of selected versions of the predetermined data sequence, for example, reversing the polarity of alternate predetermined data sequence versions a

reduction of the interference of the unwanted versions is provided with respect to the wanted version of the predetermined data sequence.

As will be appreciated from the foregoing description, in preferred embodiments, the predetermined data sequence is a PRBS. The correlation sequence
5 therefore comprises a plurality of versions of the PRBS each being shifted with respect to each other.

In preferred embodiments the data may be combined with the information material in a transform domain representation of the information material. As a result, the effect of for example a data symbol combined with a transform domain data
10 symbol may be spread over several information material data symbols, thereby reducing any perceivable effect on the information material. Any appropriate transform may be used. However, in preferred embodiments, the transform may be the discrete wavelet transform, the data symbols in the transform domain being divided into each of a plurality of sub-bands comprising wavelet coefficients, the data being
15 added to at least one of the sub-bands.

Although the information material in which the data has been embedded can be any form or type of material, in preferred embodiments the information material is video, audio or audio/video material.

Various further aspects and features of the present invention are defined in the
20 appended claims.

Brief Description of the Drawings

Figure 1 is a schematic block diagram of a watermarking system;

Figure 2 is a schematic block diagram of a watermark embedder appearing in
Figure 1;

25 Figure 3 is a schematic representation illustrating the form of the wavelet domain transform;

Figure 4 is a schematic representation of an iterative filtering process which can be used to form the wavelet transform;

Figure 5 is a schematic block diagram of a combiner forming part of the
30 watermark embedder shown in Figure 2;

Figure 6 provides an illustrative representation of a transform domain image in which data is added by the combiner shown in Figure 5;

Figure 7 is a schematic block diagram of a watermark decoder appearing in Figure 1;

5 Figure 8 is a schematic block diagram of a correlator forming part of the watermark decoder shown in Figure 7

Figure 9 is a schematic representation illustrating the formation of a correlation data sequence used by the correlator of Figure 8;

10 Figure 10 provides an illustrative representation of a transform domain image from which embedded data is to be detected and recovered;

Figure 11 is a schematic representation illustrating the operation of a data processor shown in Figure 8 performing a correlation of the correlation data sequence of Figure 9 and the transform domain data of Figure 10;

15 Figure 12 is a schematic representation illustrating the formation of a further correlation data sequence which may be used by the correlator of Figure 8;

Figure 13 is a schematic representation illustrating the operation of a data processor shown in Figure 8 performing a cross-correlation of the correlation data sequence of Figure 12 and the transform domain data of Figure 10;

20 Figures 14A and 14B are schematic block diagrams of the structure of an extended and a basic UMID respectively.

Description of Preferred Embodiments

An example embodiment of the present invention will be described with reference to a watermarking system in which data is embedded into a video image. Any type of data can be embedded into the image. However, advantageously the data
25 embedded into the image may be meta data which describes the image or identifies some attributes of the content of the image itself. An example of meta data is the Universal Material Identifier (UMID). A proposed structure for the UMID is disclosed in SMPTE Journal March 2000. A more detailed explanation of the structure of the UMID will be described later.

Watermarking System

Figure 1 illustrates a watermarking system, generally 10, for embedding a watermark into a video image 115, and recovering and removing a watermark from the video image 115. The watermarking system 10 in figure 1 comprises an image processor 100 for embedding the watermark into the video image, and a decoding image processor 102 for detecting and recovering the watermark, and for removing or 'washing' the watermark from the video image.

The image processor 100 for embedding the watermark into the video image comprises a strength adapter 180, and a watermark embedder 120. The watermark embedder 120 is arranged to embed the watermark into the video image 115, produced from the source 110, to form a watermarked image 125. The watermark to be embedded into the video image is formed from data 175 representing a UMID. Generally, the UMID identifies the content of the video image, although it will be appreciated that other types of meta data which identify the content or other attributes of the image can be used to form the watermark. In preferred embodiments the watermark embedder 120 embeds the UMID into the video image 115 in accordance with a particular application strength 185 from the strength adapter 180. The strength adapter 180 determines the magnitude of the watermark in relation to the video image 115, the application strength being determined such that the watermark may be recovered whilst minimising any effects which may be perceivable to a viewer of the watermarked image 125. After embedding the watermark, the image may be transmitted, stored or further processed in some way, such as for example, compression encoding the image. This subsequent processing and transmitting is represented generally in Figure 1 as line 122.

In Figure 1 the decoding image processor 102 for detecting and removing the watermark is shown as comprising a watermark decoder 140, a data store 150 and a watermark washer 130 which removes the watermark from the watermarked image 125.

The watermark decoder 140 detects the watermark from the watermarked video image and in the present example embodiment, generates a restored UMID 145 from the watermarked image 125. The watermark washer 130 generates a restored image

135, by removing as far as possible the watermark from the watermarked image 125. In some embodiments, the watermark washer 130 is operable to remove the watermark from the image substantially without leaving a trace. The restored image 125 may then be stored in a store 150, transmitted or routed for further processing.

5 The Watermark Embedder

The watermark embedder will now be described in more detail with reference to Figure 2, where parts also appearing in Figure 1 have the same numerical references. In Figure 2 the watermark embedder 120 comprises a pseudo-random sequence generator 220, an error correction encoder 200, a wavelet transformer 210,
10 an inverse wavelet transformer 250, a modulator 230 and a combiner 240.

The error correction encoder 200 receives the UMID 175 and generates an error correction encoded UMID comprising redundant data in combination with the UMID, in accordance with an error correction encoding scheme. It will be appreciated that various error correction coding schemes could be used to encode the UMID. For
15 the example embodiment the error correction encoder 200 uses a Bose-Chaudhuri-Hocquenghem (BCH) systematic code providing 511 bit code words comprising 248 source bits of the UMID and 263 bits of redundant parity bits.

As shown in Figure 2 the error correction encoded UMID 205 is received at a first input to the modulator 230. The pseudo-random sequence generator 220 outputs a
20 PRBS 225 which is received at a second input to the modulator 230. The modulator 230 is operable to modulate each copy of a PRBS, generated by the pseudo-random sequence generator 220, with each bit of the error correction encoded UMID. In preferred embodiments the data is modulated by representing the values of each bit of the PRBS in bipolar form ('1' as +1, and '0' as -1) and then reversing the polarity of
25 each bit of the PRBS, if the corresponding bit of the encoded UMID is a '0' and not reversing the polarity if the corresponding bit is a '1'. The modulated PRBS is then received at a first input of the combiner 240. The combiner 240 receives at a second input the image in which the PRBS modulated data is to be embedded. However the data is combined with the image in the transform domain.

30 The use of a pseudo-random sequence 225 to generate the spread spectrum signal representing the watermark data allows a reduction to be made in the strength of

the data to be embedded in the image. By cross-correlating the data in the transform domain image to which the modulated PRBS has been added, a correlation output signal is produced with a so called correlation coding gain which allows the modulated data bit to be detected and determined. As such, the strength of the data added to the image can be reduced, thereby reducing any perceivable effect on the spatial domain image. The use of a spread spectrum signal also provides an inherent improvement in robustness of the image because the data is spread across a larger number of transform domain data symbols.

As shown in Figure 2, the wavelet transformer 210 receives the video image 115 from the source 110 and outputs a wavelet image 215 to the combiner 240. The image is thus converted from the spatial to the transform domain. The combiner 240 is operable to add the PRBS modulated data to the image in the transform domain, in accordance with the application strength, provided by the strength adapter 180. The watermarked wavelet image 245 is then transformed into the spatial domain by the inverse wavelet transformer 250 to produce the watermarked image 125. The operation of the combiner 240 will be explained in more detail shortly.

In order to explain the embodiment of the present invention a brief description of wavelet transforms will be provided in the following paragraphs with reference to Figures 3 and 4.

The Wavelet Transform

Wavelets are well known and are described in for example "A Really Friendly Guide to Wavelets" by C Valens, 1999 (c.valens@mindless.com). Valens shows that the discrete wavelet transform can be implemented as an iterated filter bank, as used in sub-band coding, with scaling of the image by a factor of 2 at each iteration.

Thus, referring to Figure 3 a spatial domain image is applied to a set of high pass HP and low pass LP filters. At level 1, the first stage of filtering, the image is filtered horizontally and vertically and, in each direction, scaled down by a factor of 2. In level 2, the low pass image from level 1 is filtered and scaled in the same way as in level 1. The filtering and scaling may be repeated in subsequent levels 3 onwards.

The result is shown schematically in Figure 4. Figure 4 is a representation normal in the art. The horizontal axis H indicates increasing frequency of the sub-

bands. At level one the image is spatially filtered into four bands; the lower horizontal and vertical band, lH_1, lV_1 ; the upper horizontal band hH_1, lV_1 ; the upper vertical band lH_1, hV_1 ; and the upper horizontal and vertical band, hH_1, hV_1 . At level 2, the lower horizontal and vertical band, lH_1, lV_1 is filtered and scaled into the lower horizontal and vertical band, lH_2, lV_2 ; the upper horizontal band hH_2, lV_2 ; the upper vertical band lH_2, hV_2 ; and the upper horizontal and vertical band, hH_2, hV_2 . At level 3 (not shown in Figure 4), the lower horizontal and vertical band, lH_2, lV_2 is further filtered and scaled.

Combiner

The operation of the combiner 240 will now be explained in more detail. The combiner 240 receives the wavelet image 215 from the wavelet transformer 210, and the modulated PRBS from the modulator 230 and the application strength 185 from the strength adapter 180. The combiner 240 embeds the watermark 235 onto the wavelet image 215, by adding, for each bit of the modulated PRBS a factor α scaled by ± 1 , in dependence upon the value of the bit. Selected parts of the wavelet image 215 are used to embed the watermark 235. Each pixel of the predetermined region of the wavelet image 215 is encoded according to the following equation:

$$X'_i = X_i + \alpha_n W_n \quad (1)$$

Where X_i is the i -th wavelet coefficient, α_n is the strength for the n -th PRBS and W_n is the n -th bit of the watermark to be embedded in bipolar form, which for the example embodiment is the bit of the error correction encoded UMID.

An example of the combiner and the operation of the combiner will now be described with reference to Figures 5 and 6. In Figure 5 the combiner 240 is shown to receive the transform domain image from the connecting channel 215 which provides the transform domain image to a frame store 236. The frame store 236 is arranged to store a frame of transform domain data. The combiner 240 is also arranged to receive the spread spectrum encoded and error correction encoded UMID after it has been spread using the PRBS (modulated PRBS data). For this example embodiment one UMID in this error correction and spread spectrum encoded form is to be embedded in the frame of image data within the frame store 236. Thus, each encoded UMID forms an item of data which is to be embedded into each frame of image data. To this end,

the frame store stores a frame of data representing the image in the wavelet transform domain. The data to be embedded is received at a combining processor 237 which combines the data to be embedded into selected parts of the wavelet transform domain image stored in the frame store 236. The combiner 240 is also provided with a control processor 238 which is coupled to the combining processor 237.

In Figure 6 an illustrative representation of a first order wavelet transform is presented. This wavelet transform is representative of a frame of the image transformed into the wavelet domain and stored in the frame store 236. The wavelet transform image WT_IMG is shown to comprise four wavelet domains representative of sub-bands into which the image has been divided. The wavelets have been labelled in correspondence with the illustration provided in Figure 3. In the example embodiment of the present invention, the data to be embedded is only written into the low vertical, high horizontal frequencies sub-band hH_1lV_1 and the low horizontal, high vertical frequencies sub-bands labelled lH_1hV_1 . The data is added to these sub-bands hH_1lV_1 , lH_1hV_1 by the combining processor 237 under control of the control processor 238 as illustrated in Figure 6, according to equation (1).

By embedding the data in only the two sub-bands hH_1lV_1 , lH_1hV_1 , the likelihood of detecting the embedded data is improved whilst the effects that the embedded data will have on the resulting image are reduced. This is because the wavelet coefficients of the high horizontal, high vertical frequencies sub-bands hH_1hV_1 are more likely to be disturbed, by for example compression encoding. Compression encoding processes such as JPEG (Joint Photographic Experts Group) operate to compression encode images by reducing the high frequency components of the image. Therefore, writing the data into this sub-band hH_1hV_1 would reduce the likelihood of being able to recover the embedded data. Conversely, data is also not written into the low vertical, low horizontal frequencies sub-band lH_1lV_1 . This is because the human eye is more sensitive to the low frequency components of the image. Therefore, writing the data in the low vertical, low horizontal frequencies sub-band would have a more disturbing effect on the image. As a compromise the data is

added into the high horizontal, low vertical frequencies sub-band hH_1lV_1 and the low horizontal, high vertical frequencies sub-bands lH_1hV_1 .

As already explained, an effect of processing the image in the spatial or the transform domains is to shift the wavelet coefficients in the sub-band with an effect that the relative position of the wavelet coefficients within the sub-bands differ from their original positions. This is illustrated in Figure 6, by the double headed arrows SHFT. Since the processing which may be performed on the image is unknown, the amount of the shift of the sub-band coefficients will be unknown. As a result, the modulated version of the PRBSs added to the wavelet coefficients of the sub-band will no longer align, and will have been shifted with respect to a PRBS generated by a detector, which is expecting the modulated PRBS versions to be at the same position as they were when the modulated PRBSs were added to the sub-band by the data embedder. As a result the cross-correlation of wavelet coefficients with the reproduced PRBS will produce a low or zero value from which the embedded data is unlikely to be detectable.

Decoder

The operation of the watermark decoder 140 in the decoding image processor will now be explained in more detail, with reference to Figure 7, where parts also appearing in Figure 1 bear identical reference numerals. The watermark decoder 140 receives the watermarked image 125 and outputs a restored version of the UMID 145. The watermark decoder 140 comprises a wavelet transformer 310, a pseudo-random sequence generator 320, a correlator 330, a selector 340 and an error correction decoder 350.

The wavelet transformer 310 converts the watermarked image 125 into the transform domain so that the watermark data can be recovered. The wavelet coefficients to which the PRBS modulated data were added by the combiner 240 are then read from the two wavelet sub-bands hH_1lV_1 , lH_1hV_1 in the reverse direction to the direction in which the data was added in the combiner 240. These wavelet coefficients are then correlated with respect to the corresponding PRBS used in the watermark embedder. Generally, this correlation is expressed as equation (2), below,

where X_n is the n -th wavelet coefficient and R_n is the R -th bit of the PRBS generated by the Pseudo Random Sequence Generator 320.

$$C_n = \sum_{i=1}^s X_{sn+i} R_i \quad (2)$$

The relative sign of the result of the correlation C_n then gives an indication of the value of the bit of the embed data in correspondence with the sign used to represent this bit in the watermark embedder. The data bits recovered in this way represent the error correction encoded UMID which is subsequently decoded by the error correction decoder 350 using a decoding algorithm for the error correction code used by the encoder 200. Having recovered the UMID, the watermark can be removed from the video image by the watermark washer 130, by performing the reverse of the operations performed by the embedder. The correlator 330 appearing in Figure 7 is shown in more detail in Figure 8, wherein parts also appearing in Figure 7 bear identical numerical references.

In Figure 8 the correlator 330 is shown to comprise a frame store 331 which is arranged to receive the wavelet transformed image via the connecting channel 315. The frame store 331 is arranged to store a frame of wavelet transformed image. A data sequence processor 332 is arranged to receive the PRBS from the PRBS generator 320 and to feed this PRBS in sync with a timing signal received from a correlation processor 333, via timing channel 336. The correlation processor 333 controls the correlation of the data symbols (wavelet coefficients) read from the sub-band of the image in the frame store 331 with the PRBS. However, to recover the embedded data the reproduced PRBS should be aligned with the corresponding modulated version of the PRBS added to respective wavelet coefficients from the sub-band. The correlation is performed by the data processor 334, under control from the correlation processor 333, using control channel 337, and the data sequence processor 332.

First Embodiment

Embodiments of the present invention address a technical problem of recovering the embedded data from the wavelet coefficients if there has been a shift in the wavelet coefficients in the sub-band. As already explained such a shift can occur if the image has been processed and can occur when the image is transformed from the

spatial domain to the transform domain. If the wavelet transform coefficients have shifted within the sub-band, then the PRBS will no longer be aligned with the version of the PRBS which has been added to the wavelet coefficients within the sub-band. As a result, the correlation with the reproduced PRBS will not provide a correlation output signal from which the embedded data symbols are detectable. This is addressed by
5 embodiments of the present invention by generating a composite sequence hereinafter referred to as a correlation data sequence and correlating this with respect to the data within the sub-band. The correlation data sequence is formed as illustrated in Figure 9.

10 As illustrated in Figure 9 a number of copies of the PRBS used to embed the data in the transform domain are generated by the PRBS generator 320 and fed via the connecting channel 325 to the data sequence processor 332. The number of PRBS copies generated corresponds to the number of possible shifts of the data within the sub-band which can be tolerated. For each of these tolerated shifts, the embedded data
15 may still be recovered. As illustrated in Figure 9 the possible integer shifts INT_SHFT are shown alongside a corresponding version of the PRBS which has been shifted with respect to a central PRBS CENT_P. Effectively, therefore for the illustrative embodiment shown in Figure 9, a shift of ± 2 symbols can be tolerated and the embedded data symbols can still be detected from the output of the correlation signal.
20 The five versions of the PRBS at each of $-2, -1, 0, +1, +2$ shifts are then combined together to form a composite data sequence which forms the correlation data sequence CORR_SEQ. It is the correlation data sequence CORR_SEQ which is supplied by the data sequence processor 332 to the data processor 334 under control of the correlation processor 333 to generate the correlation output from which the embedded data
25 symbols can be recovered.

In Figure 10 the data embedded within the high horizontal, low vertical frequencies sub-band hH_1lV_1 is represented as a sequence of boxes P_SEQ representing the continuous regions for which a modulated PRBS has been added to the wavelet coefficients. The correlation processor 333 is arranged to read the wavelet
30 coefficients sequentially in correspondence with the order in which they were added to the sub-band starting with a start position ST_P from which the new PRBS is assumed to start. An arrow R1 represents the order of reading the wavelet coefficients which is

performed by the correlation processor 333. The data processor 334 effectively then calculates the correlation between this set of wavelet coefficients WCT and the correlation sequence CORR_SEQ as represented schematically in Figure 11. As a result, although the wavelet coefficients within the sub-band may have been shifted
5 from their expected position, by up to ± 2 symbols, then the wavelet coefficients recovered will nevertheless align with one of the versions of the PRBS which was used to construct the correlation data sequence CORR_SEQ. As a result the data processor 334 will generate an output correlation signal for the alignment of the wavelet coefficients with the corresponding PRBS within the correlation sequence to produce a
10 signal from which the embedded data symbol can be detected. It is a property of data sequences such as PRBSs that other shifts of the PRBS will effectively appear as noise with respect to the aligned version of the PRBS which has been added to the wavelet coefficients. Since the correlation output will produce a high peak for the aligned PRBS, the embedded data symbol will still be detectable from the correlation output
15 signal in spite of the presence of the other shifted versions of the PRBS, which effectively form noise.

Second Embodiment

A further embodiment of the present invention is illustrated in Figures 12 and 13 respectively. The embedded data may have been combined with one of a plurality
20 of possible PRBSs which may not be known at the watermark decoder processor 140. What would be known is that the PRBS used to embed the data is one of a limited set of PRBSs. In this example embodiment, the correlation sequence is formed by adding together the PRBSs corresponding to the set of PRBSs which could have been used to spread spectrum encode the embedded data added to the wavelet coefficients. To this
25 end, Figure 12 illustrates such an arrangement in which the set is considered to comprise four PRBSs P1, P2, P3, P4 which are added together to form the correlation sequence CORR_SEQ¹. The correlation processor 333 then operates in exactly the same way as already explained for the first embodiment, but now correlates the recovered wavelet coefficients with the composite data sequence CORR_SEQ¹ formed
30 from combining the four different PRBSs. This is illustrated in Figure 13. Again as with the embodiment described with reference to Figures 9 and 11, the PRBS which

has been used to spread spectrum encode the embedded data will correlate with an aligned version of the modulated PRBS added to the wavelet coefficients and generate a correlation output signal from which the data processor 334 can detect the embedded data symbol. As before the other unwanted PRBSs which were not used to encode the embedded data symbols will effectively form noise to the correct PRBS. However as already explained, a property of data sequences such as PRBSs is that the correlation output for the correct PRBS, will be high enough in the presence of the other incorrect PRBSs acting as noise that the data symbol can be detectable from the resulting correlation output signal.

10 In preferred embodiments, the correlation processor 334 may be operable to form the correlation sequence in the embodiments described herein, by selecting a plurality of the shifted versions of the PRBS and reversing the polarity of the selected versions. By reversing the polarity of selected versions of the PRBSs to form the correlation data sequence, a reduction of the interference of the unwanted PRBSs to the wanted PRBS can be provided, when the correlation is performed. For example, alternate PRBSs of the correlation sequence can be combined with the polarity of alternate PRBSs versions reversed. Since the polarity of the PRBS which forms the wanted PRBS will be unknown as a result of the polarity inversions, a corresponding adjustment must be made in the decoder in order to interpret the recovered data correctly. This is because the embedded data recovered from the image may be inverted, in that each '0' will appear as a '1' and each '1' will appear as a '0'. In preferred embodiments, however, at least one symbol of predetermined polarity may be embedded into the image. This can be used to adjust the bit values recovered. This can be arranged in the correlator 330 itself, or after the error correction decoder. An advantage of applying correction of the recovered bits after error correction decoding is that the error correction code can be used to provide protection for the predetermined polarity symbol. Thus after decoding, the value of the predetermined polarity symbol is determined and compared with the value, which is known to the decoder. Appropriate correction can then be applied.

30 Other Embodiments

A further improvement can be provided to the embodiments described herein, to the effect of identifying which PRBS version from the plurality of PRBS versions from which the correlation sequence is formed should be used to recover the embedded data. To this end the data sequence processor 334 operates under the control of the correlation processor 333 to divide each of the versions of the PRBSs into two or more groups and to form correspondingly two or more correlation sequences by combining the respective PRBS versions of the groups. The correlation sequences are then correlated separately with the wavelet coefficients. The correlation sequence which produces a correlation output signal which exceeds the correlation threshold is identified. The identified correlation sequence therefore contains the wanted PRBS, the wanted PRBS being that which correctly corresponds with the version used to form the modulated data. This wanted PRBS can be used subsequently to recover the data by performing subsequent correlations. The PRBS versions from which the identified correlation sequence is comprised are then divided further into groups from which further correlation sequences are formed. The process is repeated to identify which of the correlation sequences contains the wanted PRBS. After further divisions, the wanted PRBS may be unambiguously identified. Correspondingly, the identified PRBS provides an indication of which of the shifted versions of the PRBS or which of the different PRBSs is present in the watermarked image. The identified PRBS can be used therefore for subsequent correlations without the interference caused by the unwanted PRBSs.

In further embodiments, a further correlation sequence could be formed by combining together a shifted version of each of the PRBSs P1, P2, P3, P4 to the effect that the number added together will correspond to the number of possible shifts of the wavelet coefficients within the sub-band. As such, this further embodiment will provide a facility for recovering the embedded data if the PRBS from a set of PRBSs is not known and if the wavelet coefficients within the sub-band have been shifted as a result of processing.

The Universal Material Identifier (UMID)

A brief explanation will now be given of the structure of the UMID, with reference to Figure 14A and 14B. The UMID is described in SMPTE Journal March

2000. Referring to Figures 14A an extended UMID is shown to comprise a first set of 32 bytes of a basic UMID, shown in Figure 14B and a second set of 32 bytes referred to as signature metadata. Thus the first set of 32 bytes of the extended UMID is the basic UMID. The components are:

5 •A 12-byte Universal Label to identify this as a SMPTE UMID. It defines the type of material which the UMID identifies and also defines the methods by which the globally unique Material and locally unique Instance numbers are created.

 •A 1-byte length value to define the length of the remaining part of the UMID.

 •A 3-byte Instance number which is used to distinguish between different
10 'instances' of material with the same Material number.

 •A 16-byte Material number which is used to identify each clip. Each Material number is the same for related instances of the same material.

 The second set of 32 bytes of the signature meta data as a set of packed meta data items used to create an extended UMID. The extended UMID comprises the
15 basic UMID followed immediately by signature meta data which comprises:

 •An 8-byte time/date code identifying the time and date of the Content Unit creation.

 •A 12-byte value which defines the spatial co-ordinates at the time of Content Unit creation.

20 •3 groups of 4-byte codes which register the country, organisation and user codes.

 More explanation of the UMID structure is provided in co-pending UK patent application number 0008432.7.

25 Various modifications may be made to the embodiments herein before described without departing from the scope of the present invention. Although in this example embodiment, the data to be embedded is added to the image in the transform domain, in alternative embodiments the data could be represented in the transform domain, inverse transformed into the spatial domain, and added to the data in the
30 transform domain.

CLAIMS

1. An apparatus for detecting and recovering data embedded in information material, said data having been embedded in said information material by modulating a predetermined data sequence with the data to be embedded to form modulated data and combining said modulated data with said information material, said apparatus comprising
- 5 a correlation processor operable in combination with a data sequence processor to form a correlation sequence, and
- 10 a data processor operable under control of the correlation processor to correlate information material data symbols, with which said modulated data have been combined, with said correlation sequence, to form a correlation output signal representing the correlation between the information material data symbols and said correlation data sequence, and to recover said embedded data from said correlation
- 15 output signal, wherein said correlation sequence comprises a plurality of predetermined data sequence versions, each version representing a possible form of the predetermined data sequence for recovering said embedded data symbols from said information material.
- 20 2. An apparatus as claimed in Claim 1, wherein each of said versions of said predetermined data sequence are the predetermined data sequence used to form said modulated data shifted with respect to one another.
- 25 3. An apparatus as claimed in Claim 2, wherein the number of said plurality of versions of said predetermined data sequences is equal to a number of possible relative shifts of the information material data symbols to which the modulated data have been added, each of said plurality of predetermined data sequences being shifted with respect to each other, each shift representing a number of symbols by which the information material data symbols may have been shifted.

4. An apparatus as claimed in Claim 1, wherein each of said predetermined data sequence versions is a different predetermined data sequence of a set of possible predetermined data sequences which may have been used to form said modulated data.

5

5. An apparatus as claimed in any preceding Claim, wherein said predetermined data sequence is a Pseudo Random Symbol or Bit Sequence.

6. An apparatus as claimed in any preceding Claim, wherein said correlation processor is operable in combination with said data sequence processor, to divide each of said predetermined data sequence versions into two or more groups, to combine the predetermined data sequence version from each group to form a corresponding plurality of correlation data sequences, said data processor being arranged to correlate said information material data symbols with which said modulated data have been combined, with each of said correlation sequences, to form, for each, a correlation output signal, and said correlation processor is operable to identify which of said groups of predetermined data sequence versions includes the predetermined data sequence version for recovering said embedded data symbols from the corresponding correlation output signal.

7. An apparatus as claimed in Claim 6, wherein said correlation processor is operable to compare said correlation output signal with a threshold and to identify which of said groups includes the predetermined data sequence version for recovering said embedded data from the comparison.

8. An apparatus as claimed in Claims 6 or 7, wherein said correlation processor is operable to divide said identified group into further groups, each of said groups being combined to form further correlation sequences and to identify which of said further groups includes said predetermined data sequence for recovering said embedded data, said dividing and said identifying being repeated until the predetermined data sequence version for recovering said embedded data is identified.

9. An apparatus as claimed in any preceding Claim, wherein said correlation sequence is formed by selecting versions of said predetermined data sequence and reversing the polarity of said selected versions of said predetermined data sequence before combining said predetermined data sequence versions to form said correlation sequence.

10. An apparatus as claimed in any preceding Claim, wherein said data is combined with said information material by forming a transform domain representation of said data and combining said data with said information material in either said transform domain or the inverse transform domain, said apparatus comprising

a transform processor operable to generate a transform domain representation of said information material in which said data has been embedded, said correlation processor being operable to recover said embedded data symbols by correlating transform domain data symbols with which said embedded data has been combined with said correlation sequence.

11. An apparatus as claimed in Claim 10, wherein said transform is the discrete wavelet transform, the data symbols in the transform domain being divided into each of a plurality of sub-bands comprising wavelet coefficients, the data being added to at least one of the sub-bands.

12. An apparatus as claimed in any of Claims 5 to 11, wherein each bit of said PRBS is represented in bipolar form, said data to be embedded modulating the symbols of said PRBS by reversing the sign of each bit, said modulated Pseudo Random Bit Sequences being combined with respective wavelet coefficients of said sub-band.

13. An apparatus as claimed in any of Claims 10 to 12, comprising a pre-processor operable to receive said information material and to generate a shifted copy of the received information material, said transform processor being

operable to generate a transform domain version of said received information material and said shifted copy of said information material, and said correlation processor is operable to recover said embedded data by correlating said transform domain data of said received information material and said shifted copy of said information material.

5

14. An apparatus as claimed in any preceding Claim, wherein said information material is one of audio material, video material and audio/video information material.

10

15. A method for detecting and recovering data embedded in information material, said data having been embedded in said information material by modulating a predetermined data sequence with the data to be embedded to form modulated data and combining said modulated data with said information material,

15 said method comprising correlating information material data symbols to which the modulated data have been added with a correlation data sequence, to form a correlation output signal representing the correlation between the information material data symbols and said correlation data sequence, and

recovering said embedded data from said correlation output signal, wherein said correlation data sequence comprises a plurality of predetermined data sequence versions, each version representing a possible form of the predetermined data sequence for recovering said embedded data symbols from said modulated data.

16. A method as claimed in Claim 15, wherein said correlation data sequence further comprises a plurality of versions of each of the possible data sequences shifted with respect to one another.

25

17. A method as claimed in Claim 15, wherein each of said predetermined data sequence versions is a different predetermined data sequence of a set of possible predetermined data sequences which may have been used to form said modulated data.

30

18. A computer program providing computer executable instructions, which when loaded on to a data processor configures said data processor to operate as an apparatus according to any of Claims 1 to 14.

5 19. A computer program having computer executable instructions, which when loaded on to a data processor causes the data processor to perform the method according to Claims 15, 16 or 17.

10 20. A computer program product having a computer readable medium having recorded thereon information signals representative of the computer program claimed in any of Claims 18 or 19.

15 21. An apparatus for detecting and recovering as herein before described with reference to the accompanying drawings.

22. A method of recovering data embedded in information material as herein before described with reference to the accompanying drawings.

ABSTRACT**APPARATUS FOR DETECTING AND RECOVERING DATA**

An apparatus for detecting and recovering data embedded in information
5 material. the data having been embedded in the information material by modulating a
predetermined data sequence with the data to be embedded to form modulated data and
combining the modulated data with the information material. The apparatus comprises
a correlation processor operable in combination with a data sequence processor to
form a correlation sequence, and a data processor operable under control of the
10 correlation processor to correlate information material data symbols, with which the
modulated data have been combined, with the correlation sequence, to form a
correlation output signal representing the correlation between the information material
data symbols and the correlation data sequence, and to recover the embedded data
from the correlation output signal. The correlation sequence comprises a plurality of
15 predetermined data sequence versions, each version representing a possible form of the
predetermined data sequence for recovering the embedded data symbols from the
modulated data. The correlation data sequence may have a plurality of predetermined
data sequence shifted versions, shifted with respect to one another. As a result the
embedded data may be detectable from the transform domain data symbols in spite of
20 a relative shift of the transform domain data symbols. Alternatively, the
predetermined data sequence versions may be a set of different predetermined data
sequences, one of which has been used to generate the modulated data.

[Figs 8 and 9]

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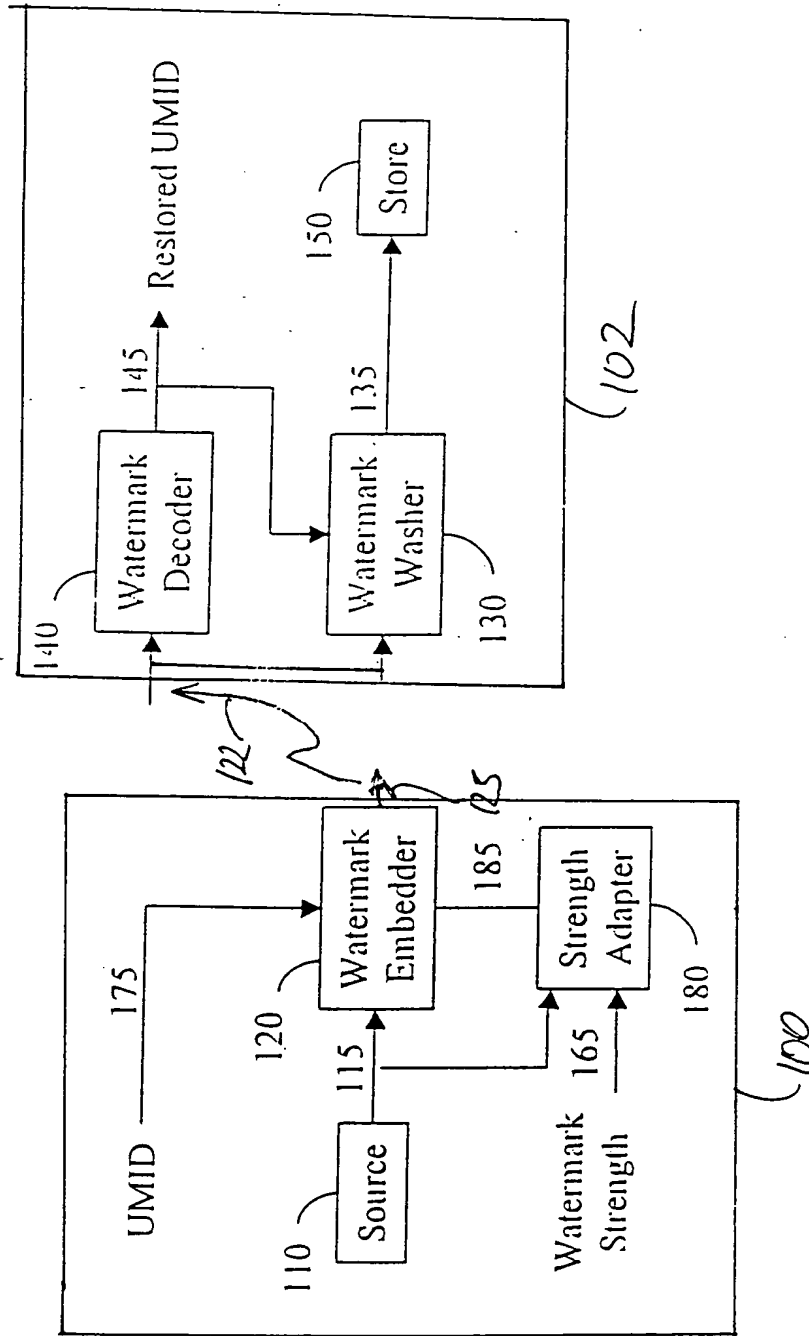


Fig. 1

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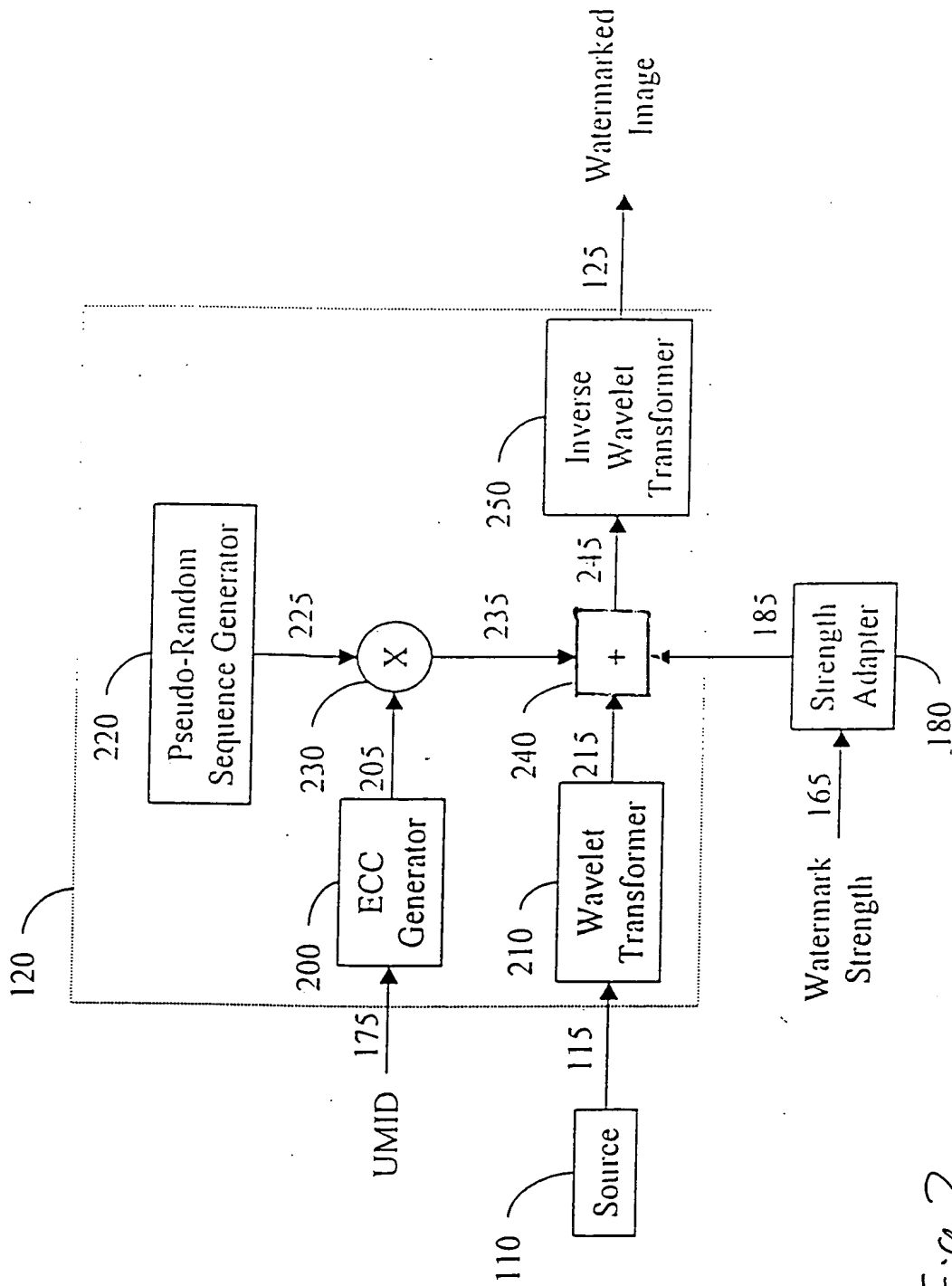


Fig 2

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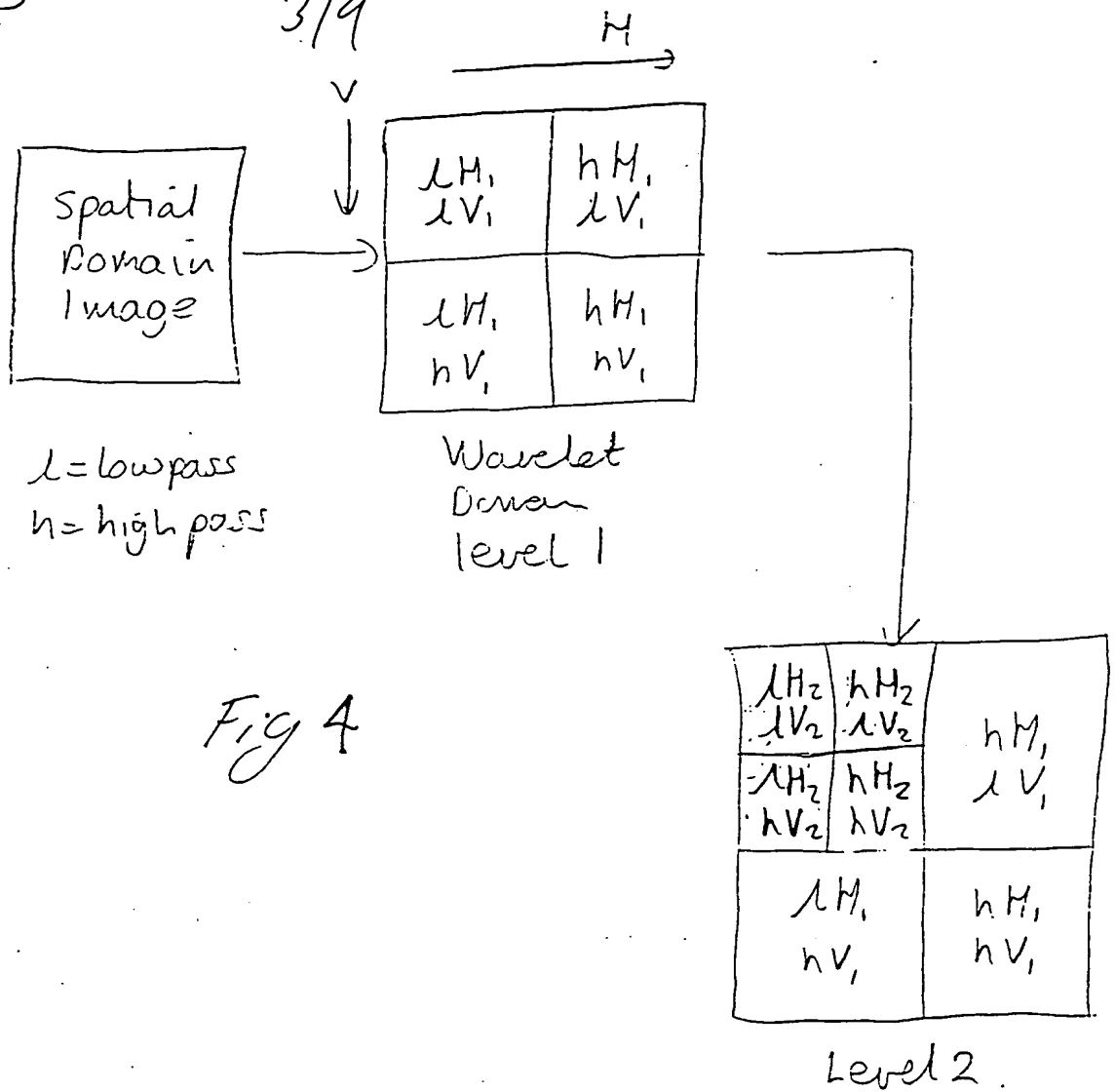


Fig 4

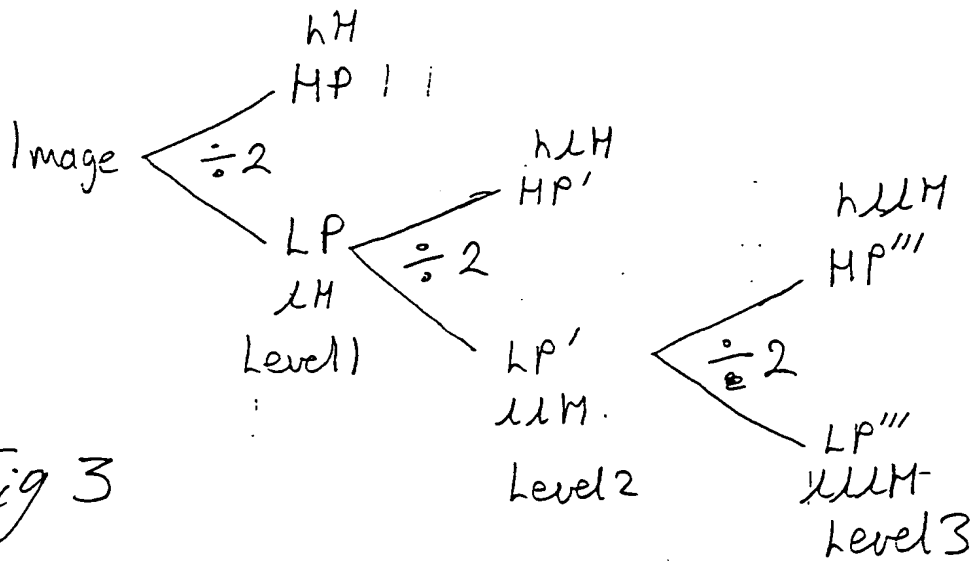


Fig 3

Schematic of Wavelet Transform.

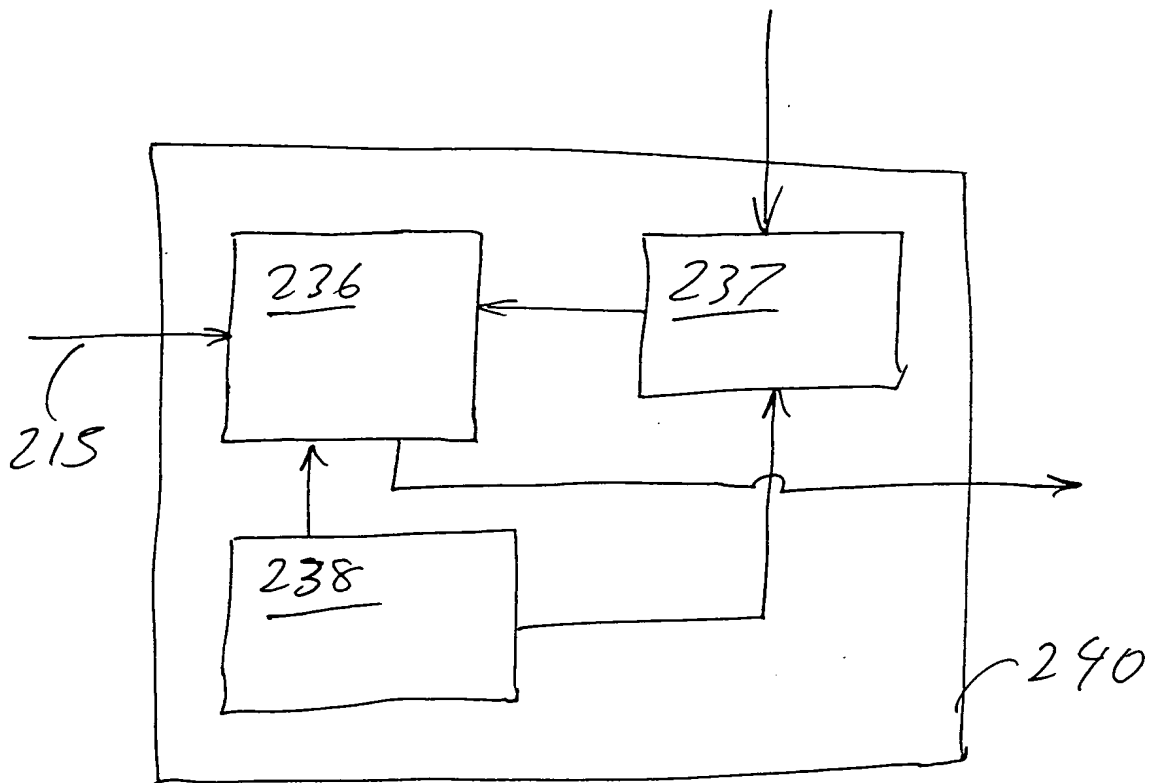


Fig. 5

WT-IMG
SHFT SHFT

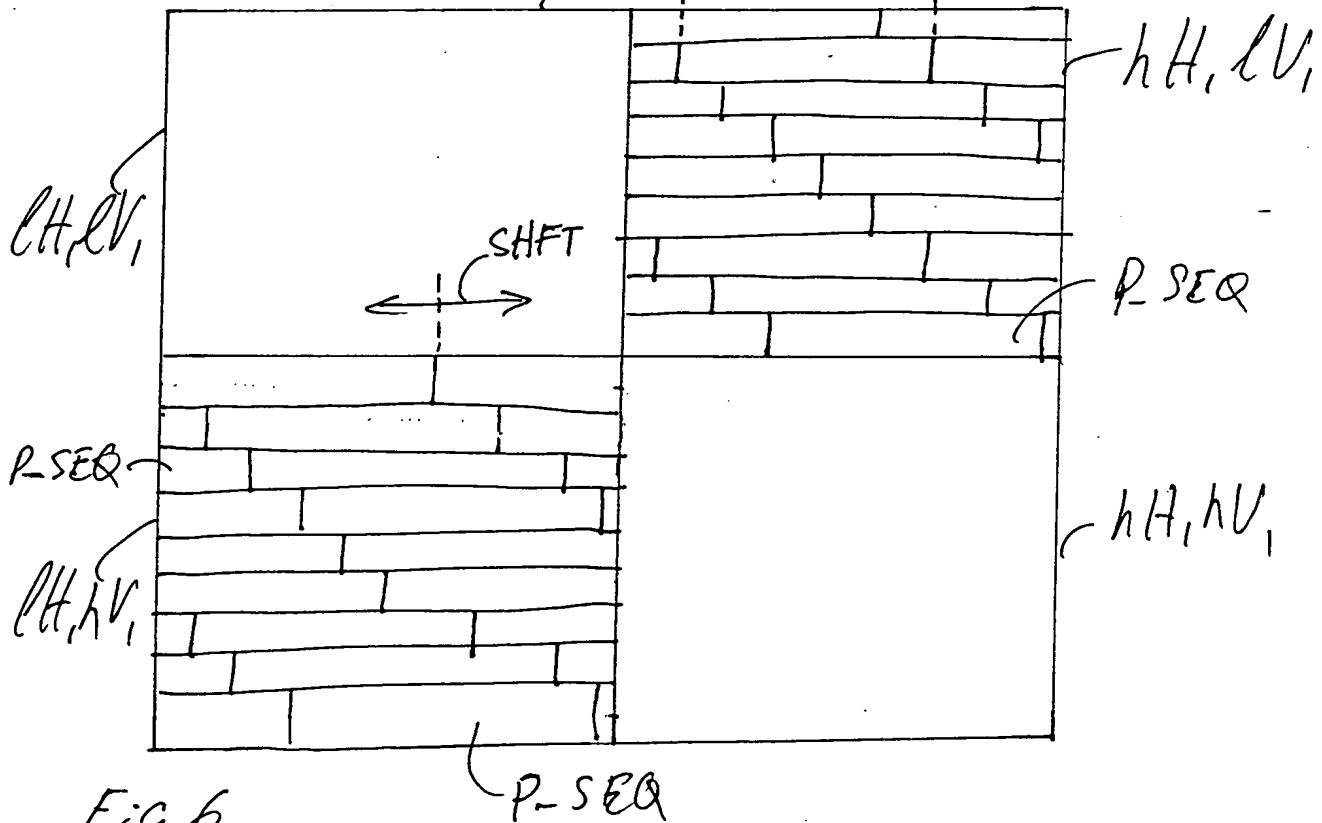


Fig 6

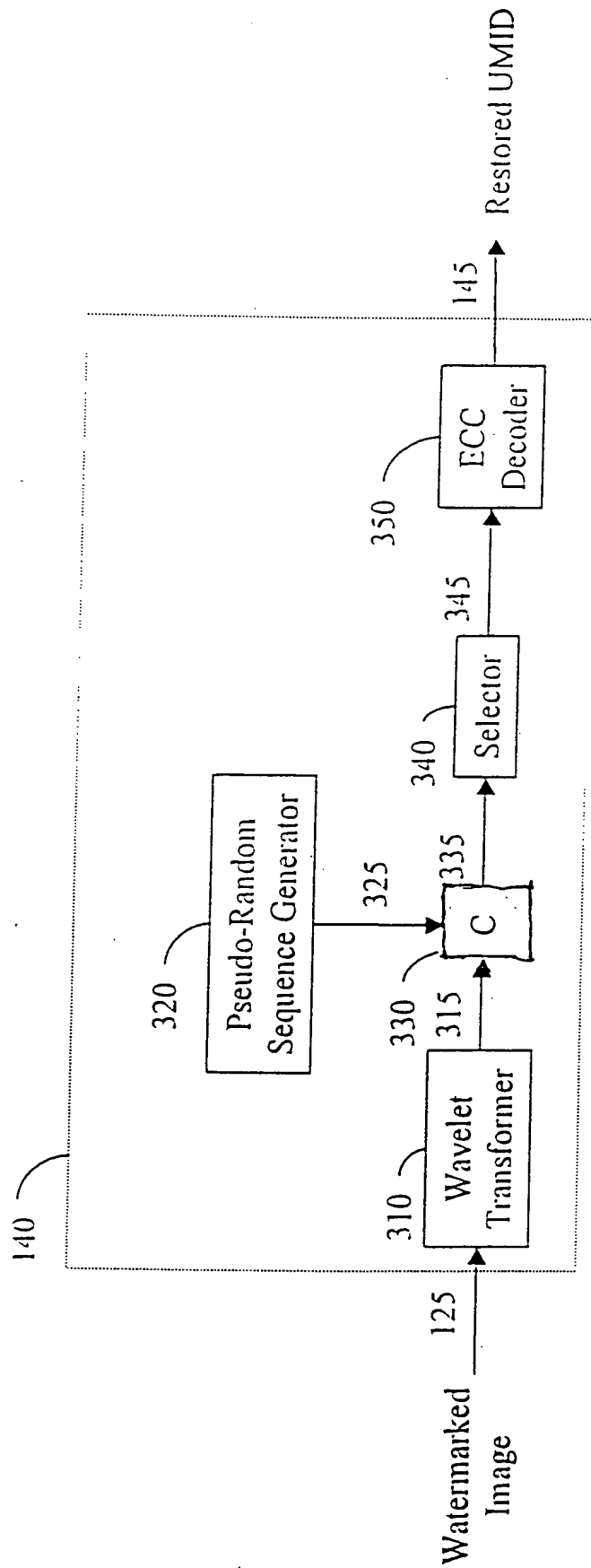
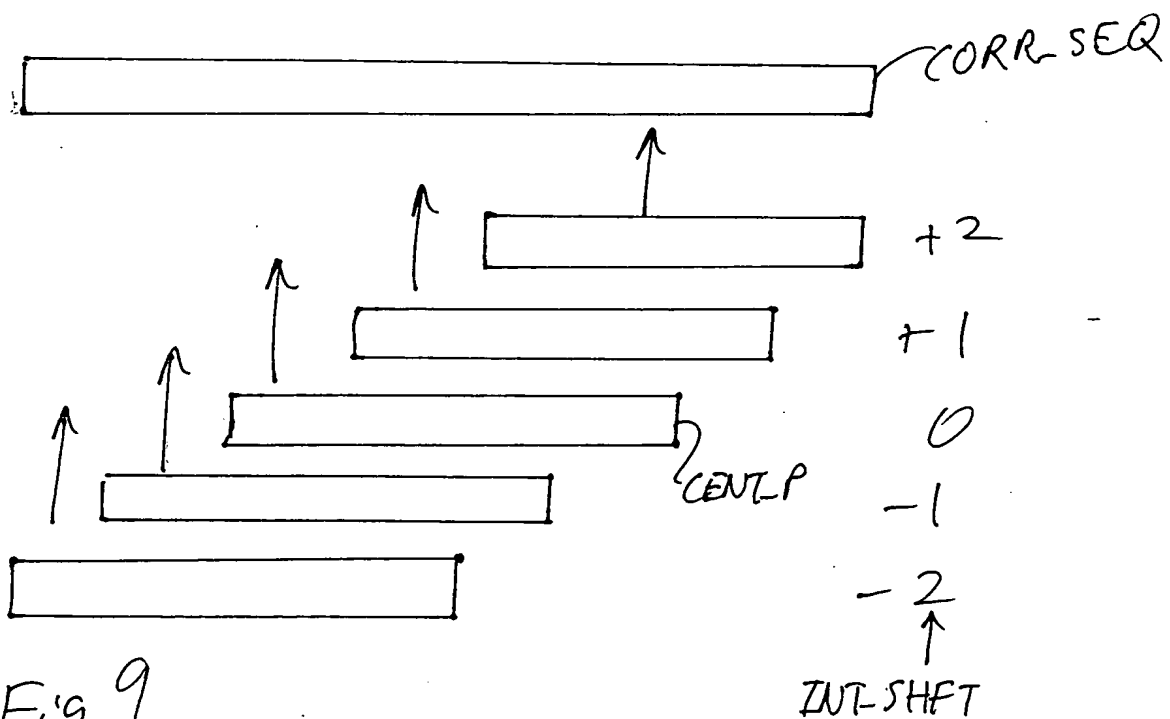
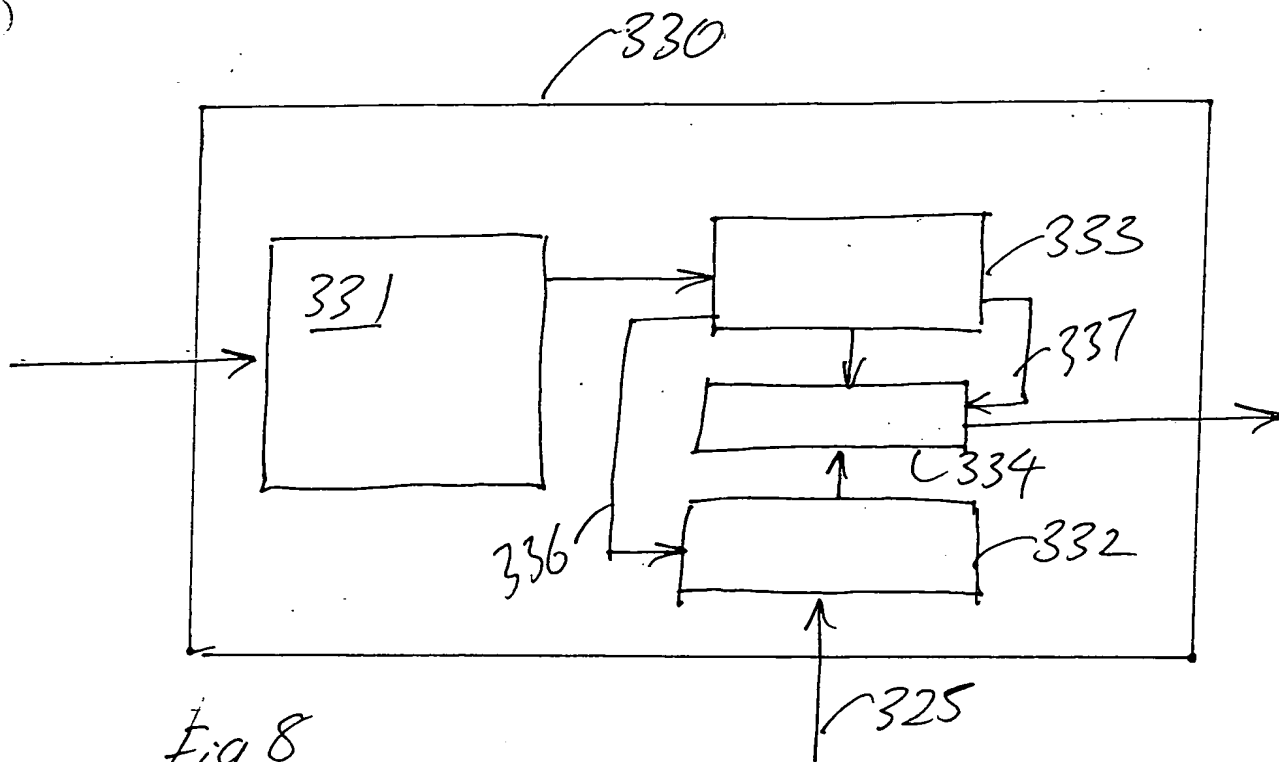
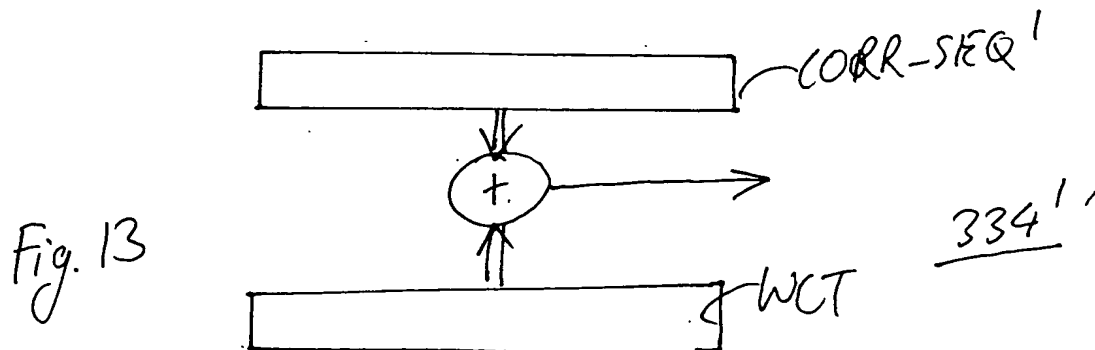
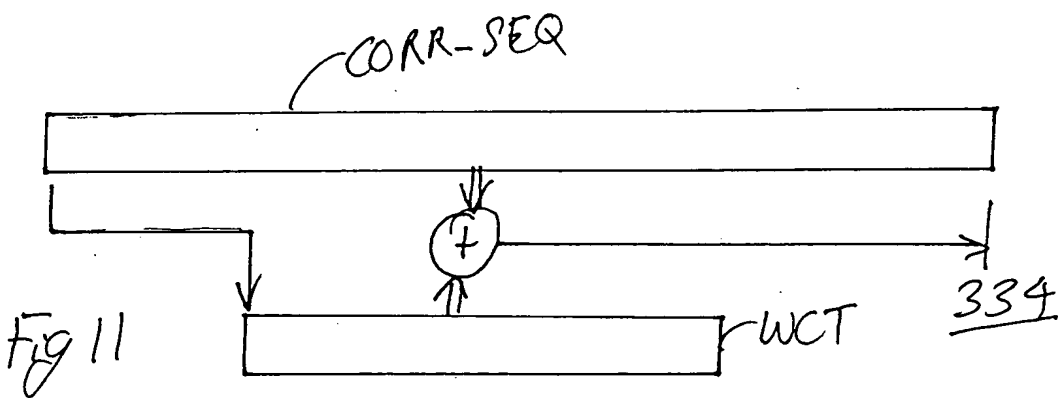
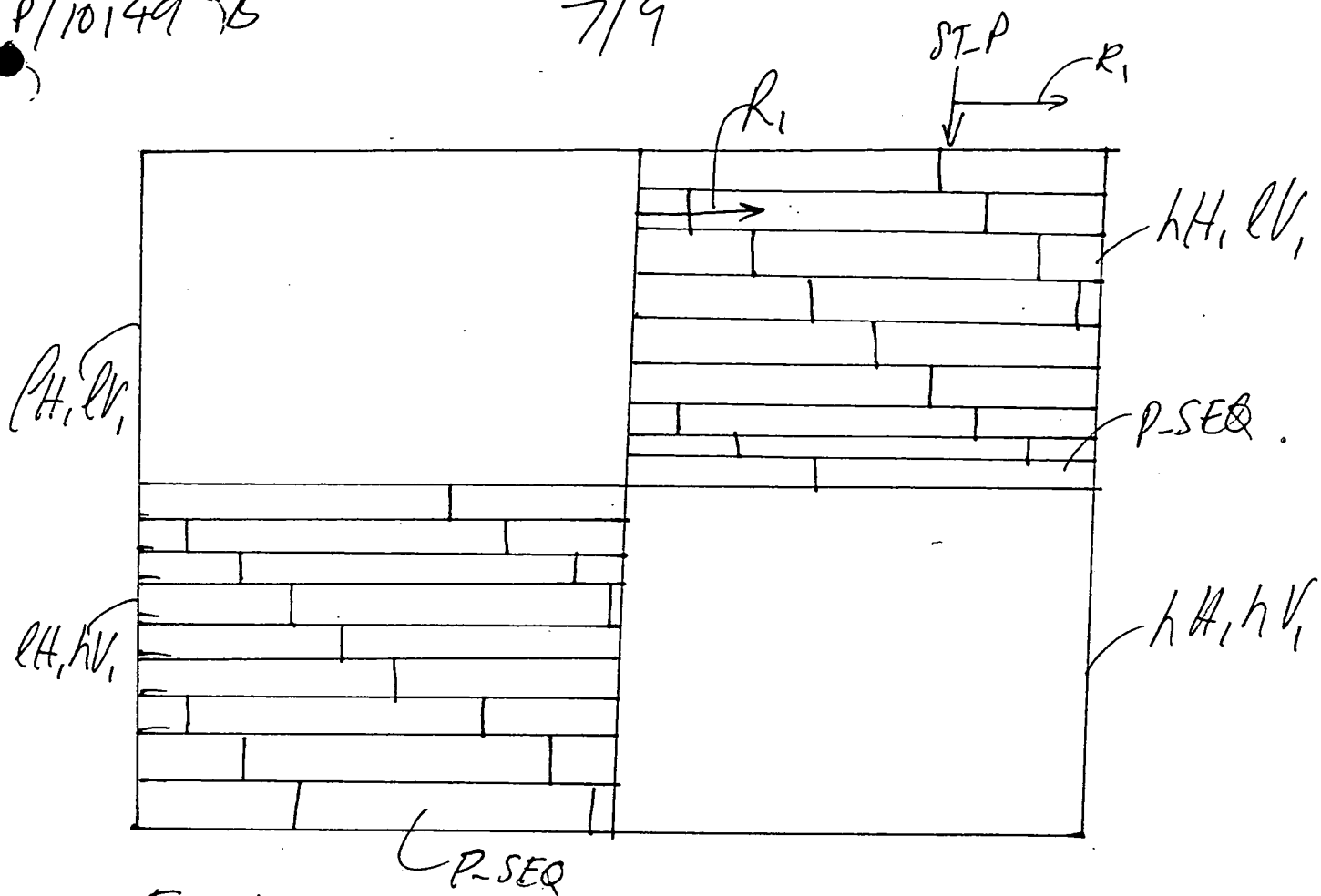


Fig. 7





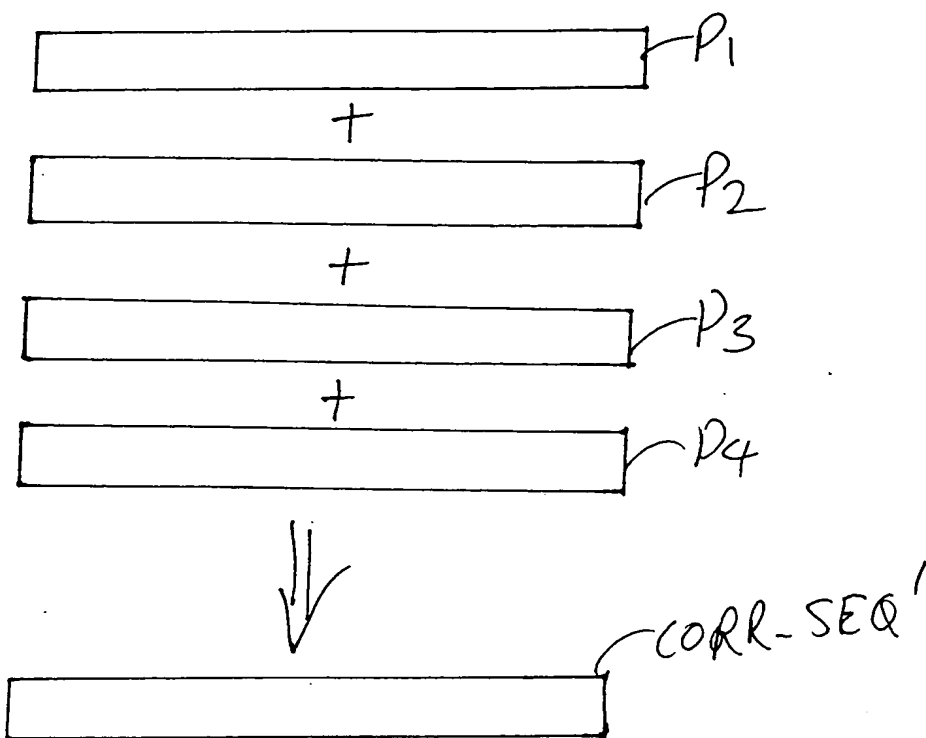


Fig. 12

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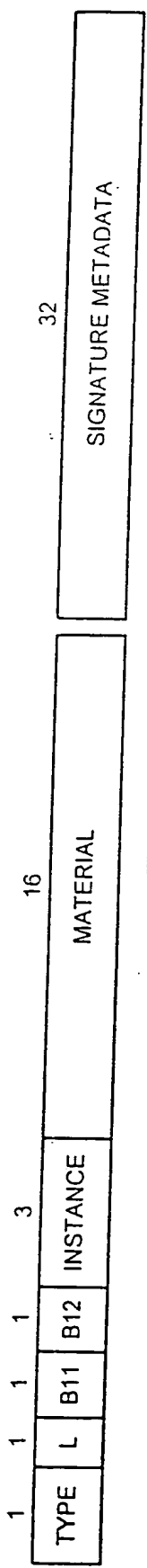


FIG. 14A

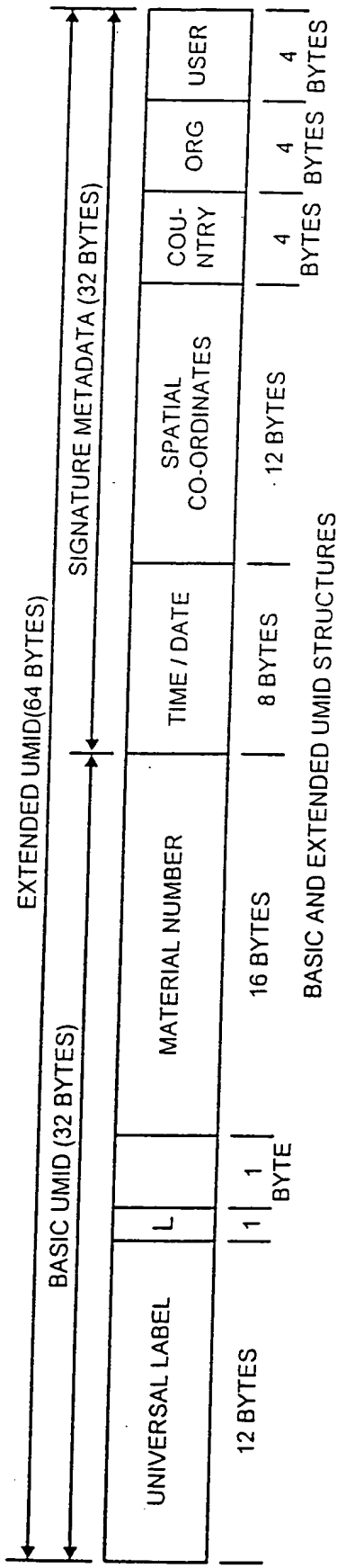


FIG. 14B